PB86-223005

Effects of Ventilation Rates and Product Loading on Organic Emission Rates from Particleboard

Acurex Corp., Research Triangle Park, NC

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Jul 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-223005

EPA/600/D-86/156
July 1986

The Effects of Ventilation Rates and Product Loading on Organic Emission Rates from Particleboard

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EPA Contract 68-02-3988

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-86/156		PB86-223005/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
The Effects of Ventilation Rates and Product Loading on Organic Emission Rates from Particleboard	July 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Leonard H. Nelms and Mark A. Mason (Acurex); and Bruce A. Tichenor (EPA/AEERL)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Acurex Corporation Research Triangle Park, North Carolina 27709	11. CONTRACT/GRANT NO. 68-02-3988
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development **Air and Energy Engineering Research Laboratory** **Research Triangle Park, NC 27711**	Published Paper; April 1986 14. SPONSORING AGENCY CODE **EPA/600/13**

15. SUPPLEMENTARY NOTES AEERL project officer is Bruce A. Tichenor, Mail Drop 54, 919/541-2991. Presented at IAQ '86, Managing Indoor Air for Health and Energy Conservation (ASHRAE), Atlanta, GA, 4/86.

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Contamination	Pollution Control	13B 14G
Particle Boards	Stationary Sources	11G
Formaldehyde	Indoor Air	07C
Research		14F
Ventilation		13A
Organic Compounds		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	**Unclassified**	36
	20. SECURITY CLASS (This page) **Unclassified**	22. PRICE $9.95

EPA Form 2220-1 (9-73)

THE EFFECTS OF VENTILATION RATES AND PRODUCT LOADING ON ORGANIC EMISSION RATES FROM PARTICLEBOARD

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ABSTRACT

Recently, investigators have confirmed the presence of varied and significant amounts of organic compounds in indoor environments, including compounds known or suspected to be health hazards. Identification of, sources of, mechanisms for entry into the environment of, and techniques for control of specific chemicals have become important research areas. A small test chamber has been used to characterize the organic emissions from building materials and consumer products. A variety of materials, including wood products, have been tested.

Based on tests of particleboard, the effects of changing ventilation rate and sample loading on airborne concentrations of specific organic compounds and their emission rates are presented. Standard test conditions of 23°C and 50% relative humidity were maintained throughout the experiment. Air exchange rates varied between 0.5 and 4 changes per hour and sample loading between 0.35 and 2.0 m^2/m^3 (board surface area/chamber volume). Concentrations of organic compounds detected are presented. The relationship between increasing formaldehyde concentrations and decreasing emission rates is discussed.

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NOTICE

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INTRODUCTION

Recently there has been an increased awareness of problems caused by the emissions of organic and inorganic chemicals inside both residential and commercial buildings (Repace 1982; Spengler and Sexton 1983). The phenomena which have been collectively described as the "sick building syndrome," among other things, have recently become a prime research area of the U.S. EPA. The Agency has begun a research program within the Air and Energy Engineering Research Laboratory to characterize the emissions of organic chemicals into the indoor environment by various products. The program involves the use of small (166 L or 5.88 ft^3) test chambers and has been described by Sanchez, et al. (1986).

The research underway or planned for this facility includes studies that will determine rates of emission for various volatile and semivolatile organic compounds from a number of products normally found in homes and office buildings. These include building materials, home or office furnishings, consumer products, and other potential sources of chemical contaminants. Several of these studies have been concluded and are reported elsewhere (Tichenor et al. 1986; Tichenor and Mason 1986). This paper addresses the organic emissions from a pressed wood product, namely particleboard. The effects of product loading and ventilation on the concentrations of the various organic species observed are shown. Efforts were directed at determining what effects on absolute concentration as well as emission rates of the organic compounds were observed as ventilation rates and product loading (m^2/m^3) were varied.

EXPERIMENTAL DESIGN

The results presented here were developed as part of an interlaboratory comparison experiment which had two objectives:

1. To examine the rates of emission of organic species which were identified as contaminants in the particleboard matrix.
2. To provide a comparison of the results obtained at two separate laboratories which determined formaldehyde emission from a material using similar but slightly different small environmental test chambers.

The experimental approach for the latter was based on the studies of Matthews, Hawthorne, et al. (1983) and was planned jointly with his group. Results of the interlaboratory comparison of formaldehyde emissions will be presented in a future paper.

A sample of particleboard was obtained from a local vendor in April 1985, eight months prior to chamber testing. The sample was not a "low formaldehyde" product, and was taken from current inventory. The original 1.22 m by 2.44 m by 16 mm (4 ft by 8 ft by 0.625 in) panel was cut into squares about 61 cm (24 in) on a side, ten days after the material was purchased. These squares were subdivided by sawing them into specimens of equal area immediately prior to starting these experiments. These were rectangles approximately 14 cm by 23 cm (5.5 in x 9.1 in) with a standard area of 0.065 m^2 (101 in^2). These specimens were used during the course of the project for testing purposes. In order to minimize the effects of intraboard variation for the interlaboratory study, the pieces were divided into two subsets. These subsets consisted of boards selected at random from the master set cut from the original panel. Each specimen was numbered for reference purposes.

Each square of particleboard from the first cutting was wrapped in clean aluminum foil and stored in a freezer at below -10°C (14 F). When the samples were prepared for testing in the chamber, the four outer edges were carefully sealed. Other workers have used paraffin wax as an edge seal. This was investigated and found to be a source of hydrocarbon contamination. Another material, sodium silicate, was investigated and found to be satisfactory. The sodium silicate was applied to the edges, where it quickly hardened to form a glass-like coating. This glassy layer prevented direct mass transfer of organic matter from within the board to the air through newly cut edges.

Prior to testing, the two sets of boards were removed from the freezer and allowed to reach room temperature. They were then unwrapped and placed in a conditioning chamber. Clean air at 23°C (73 F) and 50% relative humidity (RH) was passed over the boards for approximately 10 weeks at a flow rate sufficient to keep the formaldehyde concentration in the chamber exhaust below 200 parts-per-billion by volume (ppbv). After this time, the boards were shipped to the laboratories for testing in the two small chambers.

Before initiating testing of the particleboard in the test chambers, screening studies were performed on a portion of the material. These studies involved the collection of air samples from the headspace over the particleboard fragments, followed by separation by gas chromatography and detection by mass spectrometry (GC/MS). The procedures utilized for this testing were developed and are described by Merrill, et al. (1986). This effort produced preliminary identification of most of the prevalent organic compounds emitted from the sample, allowing acquisition of standards for quantification of the organics observed by gas chromatography (GC) with flame ionization detection (FID).

The particleboard samples were tested in the environmental chambers according to a predefined scheme. The test program involved varying the material loading (L) and air exchange rates (N). Four test conditions were established, as shown in Table 1. All of the tests were carried out at 23°C and 50% RH. These tests were run simultaneously at both laboratories, using the two sets of samples. Then, the sample sets were exchanged and testing was repeated, to provide comparison between the two chambers unbiased by intraboard variables.

TEST PROCEDURES

Testing of the particleboard was carried out in two phases. The material was screened by GC/MS to identify the organic compounds emitted. This was done several months prior to the start of chamber testing. During this phase of the program, the chromatographic column and analysis procedure were selected. Any other methods development necessary for the study was also done at this time. After this was complete, pure standard compounds were purchased to allow quantification of the GC data. The chamber testing was initiated after receipt of these standards.

Material Screening

The material screening was done using GC/MS for identification of the organic compounds emitted by the particleboard. Since the rate of emission from particleboard was rather low, the samples had to be concentrated. This was accomplished by sealing several pieces of the material in a Teflon chamber and flowing ultrapure nitrogen through the system at a constant flow rate. This air

passed through a Tenax trap as it exited the Teflon container. Most of the organic compounds that were emitted during the time when this sampling was done were trapped on the Tenax. Very volatile gaseous species (such as methane, ethane, and formaldehyde) were not trapped quantitatively on the Tenax sorbent.

Following collection of the sample, the Tenax trap was removed and placed in a clamshell oven for thermal desorption. The Tenax was heated rapidly to about 220°C. The organics contained on the Tenax were swept from the trap into a purge-and-trap device, as described by Bellar and Lichtenberg (1974). This unit had a much smaller trap, containing Tenax and other sorbents, and was used to focus the organics into a smaller sample volume. This trap was in turn thermally desorbed onto the analytical column of the GC/MS.

For the analysis, a 1.8 m (6 ft) long, 3 mm (1/8 in) OD stainless steel column packed with 1% SP-1000 on Carbopak B was used. This was the same column recommended for analysis of volatile organic compounds in a number of EPA methods (EPA 1982(a); EPA 1982(b)). The column was held at 40°C for the first three minutes of the desorption cycle. This trapped the less volatile materials near the column inlet. The column was then temperature programmed at 10°C per minute to a final temperature of 200°C. The temperature was held at this value until all peaks were eluted into the MS detector of the system.

Mass spectra of the compounds eluted from the GC were collected and stored for analysis after the run was completed. These were analyzed by matching the spectra to those found in the library of mass spectra in the data processing system, where possible. Other interpretations were done using the "Eight Peak Index of Mass Spectra" (Mass Spectrometry Data Centre 1974) and by manual interpretation of the data.

Following these interpretations, confirmation of the peak identity was carried out for several of the compounds. This was accomplished by injection of a solution containing the compound of interest and comparing both the mass spectrum produced and the retention time on column to those obtained from the sample. When both of these parameters matched, identity of the compound was considered to be confirmed.

Chamber Testing

The EPA Environmental Test Chamber (ETC) facility is shown schematically in Figure 1. Compressed air was supplied by an oilless compressor at 414 kPa (60 psi). Moisture was removed by a Permapure dryer. The dry air was cleaned by passage through catalytic oxidizers, where any residual hydrocarbons were converted to carbon dioxide and water. Air flow was both regulated and monitored by a mass flow controller device incorporated in the system. The mass flow controllers were calibrated against a soap bubble flow meter prior to use. Flows were set by the process control computer and monitored throughout the experiment. The airstream was then rehumidified by addition of ultrapure water at a known volumetric rate using a syringe pump. The air was heated and then conditioned to the desired temperature before it was allowed to enter the test chamber.

The test chamber was a stainless steel cube, 0.55 m (1.8 ft) on each side, having a volume of 166 L (5.88 ft^3) with an access door on the front. Door seals were made with a gasket of EPDM rubber, an inert elastomer which showed no contribution to the organic background in the chamber. All inner surfaces of the chamber were electropolished to minimize the surface area of the walls and to make cleaning the chamber easier. One or two chambers were housed in an

incubator for control of temperature during the experimental work. Air inside each chamber was mixed by an externally driven paddle fan, turning at a constant speed of approximately 80 rpm.

The experiments were run using an internal standard method for calculation of the amount of material found in each sample. A constant amount of a compound known to elute in a region of the chromatogram that had no significant interferences was added to the exhaust from the chamber. For these tests, this internal standard was n-hexane produced by a permeation tube. The device was kept in a permeation oven at a constant temperature while a clean air stream was passed through the oven chamber at a constant flow rate. This air was subsequently added to the chamber exhaust using a standard gas mixing bulb. This bulb also served to ensure uniform mixing of the gas flowing into the glass sampling manifold.

The particleboard specimens were placed in the environmental test chamber and allowed to equilibrate for a minimum of 24 hours prior to the beginning of the test program. This allowed the samples to reach temperature and moisture equilibrium under the conditions of the test prior to the collection of data. There was no need to implement immediate testing for these samples since concentrations of compounds emitted by the sample did not fall rapidly. When the test program commenced, exhaust air was taken from the sampling manifold for analysis.

Formaldehyde was determined using an automated colorimetric analysis system manufactured by CEA Instruments. The principle of this method is the reaction of formaldehyde, sulfite, and pararosaniline to form a product which has a characteristic colorimetric response. A sample of the chamber exhaust is passed through the absorbing reagent at a known flow rate of approximately 1 L/min.

Any formaldehyde contained in the air stream is dissolved and retained in the reagent. A known amount of pararosaniline reagent is added to the sample/absorbing reagent, mixed, and allowed to react and form a characteristic colored reaction product. This mixture then flows through a cell where the absorbance of the solution is determined. The instrument electronically converts the absorbance to an output voltage that is proportional to the concentration of formaldehyde in the original air stream. The electronic signal was monitored through the analog-to-digital (A/D) converter of a Cyborg data acquisition and control device interfaced to an IBM microcomputer. The data collected were stored by this system for later retrieval and evaluation.

The data for specific organic compounds were obtained using a sample collection and concentration system followed by gas chromatographic determination of the species present. The samples were collected by drawing a portion of the chamber exhaust through Tenax resin contained in glass tubes using an air pump. The volume of sample collected was determined by using the sampling rate determined by a calibrated mass flow controller and the duration of sampling. The general techniques used were very similar to those described for use in sampling stack gases and other sources, with the Volatile Organic Sampling Train (VOST) developed by the EPA (Hansen, 1984). The VOST tubes used were of the "In-In" design described in this reference. A block diagram of the sampling system is provided in Figure 2.

Following collection of a sample, the sorbent tubes were removed from the system and capped with impervious end plugs until the analysis was performed. At that time, a glass tube was placed in the desorption system which consisted of a clamshell heater and a purge-and-trap concentrator device. The purge-and-trap device has been slightly modified to meet the specific needs of this project. High purity helium was passed through the Tenax resin to purge out any residual

moisture that may be retained on the Tenax sorbent. Then the trap was heated rapidly to about 195°C while the gas flow swept the organics that were released by the resin out of the tube and into the purge-and-trap unit for focusing. There the organics were trapped for a second time on Tenax, using much less of the resin, to focus them into a smaller volume for chromatographic analysis. This was accomplished as described in the VOST procedure.

After focusing of the organics on the second Tenax trap, the sample was analyzed. This was done by a procedure that is similar to EPA Method 624 (EPA 1982(b)). The Tenax trap in the purge-and-trap device was rapidly heated to a temperature of 190°C. Then the carrier gas flow of the GC was diverted through the trap. This swept the sample from the trap onto the analytical column of the GC. Since the identities of the compounds of interest were primarily volatile organics with boiling points of 150°C or less, the standard column described in EPA Method 624 was selected. This column was a 1.8 m (6 ft) long 2 mm (1/8 in) OD stainless steel tube packed with 1% SP-1000 on Carbopak B, equivalent to that used for the GC/MS screening studies. The initial temperature of the column was 50°C. After five minutes of desorption, the column temperature was programmed at 8°C/min to a final temperature of 225°C and held at that value for the remainder of the analysis.

Chromatographic data were acquired and evaluated using a microprocessor-based data station. This unit incorporated an electronic integrator and the manufacturer's chromatography software package for data processing. Chromatograms of standards were collected to facilitate peak identification and to develop response curves of the detector for each of the compounds of interest. These standards were prepared by weighing a small quantity of each of the highly purified compounds into a volumetric flask partially filled with methanol and diluting the material to a known volume with the solvent. Where

necessary, subsequent dilutions of this stock were made using volumetric techniques. Aliquots of this solution were taken and spiked onto a Tenax tube in the gas phase, using the heated vaporization port of the purge-and-trap device. These samples were analyzed in exactly the same manner as were the standards. For each compound present in a standard, a corresponding peak was observed in the plot of the detector signal output. The area under this peak was determined by the peak integration portion of the chromatography software. GC responses to standards at several different concentration levels were obtained and used to determine the response curve for each component of the actual sample. These response curves were then used for calculating the quantity of every material of interest in each sample analyzed, using the internal standard technique.

Theory

Emission rates from materials are dependent on a number of phenomena. Some of these are:

1. The concentration of the contaminant in the material.
2. The rate of evaporation of the contaminant from the surface of the material.
3. The rate of diffusion of the contaminant within the material.

These then are controlled by chemical and physical principles that determine the effect that each has on the emission rate. By understanding the ways that these interact, we can in the future formulate models which can be used to determine these rates based on data obtained in environmental test chamber studies.

The concentration of contaminant in a material is generally determined by the process through which it is manufactured or formulated. For particleboard,

testing has shown that the material is relatively uniform in formaldehyde emission rate within a single board (Matthews, Daffron, et al. 1983). Since the manufacture of this product generally involves hardening of a mixture of wood particles and resin, this result is not surprising. In fact, at the time of manufacture, the concentration of every contaminant in the board should be uniform throughout the piece.

As soon as the board is produced, volatile components in the matrix begin to evaporate from the outer surfaces. The rate of evaporation is related to the solubility of the gas in the particleboard. This solubility depends on such factors as the vapor pressure of the compound and the affinity or binding capacity of the solid matrix for the compound. Thus, evaporation becomes a function of the difference in concentration of the gas at the surface of the board and the concentration of gas in the overlying air. This concentration difference is multiplied by a mass transfer coefficient to obtain the evaporation rate. The mass transfer coefficient is a function of the geometry of the system and mixing in the overlying air. This mass transfer can occur via molecular diffusion, turbulent (eddy) diffusion, and convection.

Finally, the rate of diffusion of molecular species through the solid matrix will affect the emission rates. As molecules evaporate from the surface of the particleboard, a concentration gradient within the board is developed. The surface concentration decreases and lowers the driving force for emission. If no diffusion occurred in the material, the surface would soon become devoid of material that could be emitted and emission rates would fall to zero. As the equilibrium is established, the emission rate from the product will decline at a rate that is dependent on the rate at which material diffuses to the surface where evaporation can occur. This diffusion is driven by the concentration gradient according to Le Chatelier's Principle.

Calculations

The internal standard method of calculating GC results is based on the addition of a constant amount of an internal standard to the sample. This value is then used to establish a recovery for the sample itself. The amount of each component recovered is determined by:

$$C_x = A_x * R_x * C_{ia} / C_{im} \quad (1)$$

where:

C_x = concentration of component x ($\mu g/m^3$)

A_x = peak area for component x (counts)

R_x = response factor for component x ($\mu g/m^3 \cdot$count)

C_{ia} = actual concentration of internal standard ($\mu g/m^3$)

C_{im} = measured concentration of internal standard ($\mu g/m^3$)

Emission rates were determined by:

$$R_x = C_x * F / A \quad (2)$$

where: R_x = emission rate for component x ($\mu g/m^2 \cdot hr$)

C_x = concentration of component x ($\mu g/m^3$)

F = flow rate through chamber (m^3/hr)

A = area of the sample (m^2)

RESULTS

The GC/MS screening tests run on the particleboard samples detected some 21 discrete organic compounds with masses greater than 40 AMU. These components could not all be identified using the standard techniques employed by the screening laboratory. A sample chromatogram from one of the GC/MS runs is presented in Figure 3a. On this figure, the tentative peak identifications which were made are shown. The entire list of compounds and available information about them is found in Table 2. Eight of these compounds, as indicated, have been confirmed by the technique of matching the retention time and the mass spectrum of the known material to that of the unknown component in the sample. Identities of the other compounds are tentative as they are based on mass spectral matches alone. It should be noted that none of these test procedures would detect or confirm the presence of formaldehyde in the samples, since its molecular weight (30) was lower than the minimum mass scanned during the GC/MS analytical program.

Results obtained from the chamber tests are presented in Table 3 for the materials that were quantified by the procedures used in the analyses. Seven components were identified and quantified for each test run. A chromatogram of a representative run is found in Figure 3b. Peaks identified and quantified are labeled on the figure. The hexane peak used as an internal standard is labeled "I.S.". These components were analyzed on two occasions during each of the two tests, and the values presented are the mean values obtained for the four runs. Table 4 contains the estimated limits of detection and quantitation for each compound. These estimates are three and ten times the apparent signal-to-noise ratio, respectively. A comparison of the quantitation limits to the data found in Table 3 indicates that some concentrations are quite close to the

quantitation limit. These low values may be less accurate than those values for components that are present in high concentrations. This is further apparent from the spread in results for the duplicate runs obtained. As shown in Table 3, formaldehyde is the component found with the highest concentration. The other materials detected were present at lower levels in all cases.

The mean value of the concentration data from two analyses for each test was used to calculate the emission rates of each organic compound detected. The average value of emission rates (on a unit area basis) and the measured standard deviation for each experiment are listed in Table 5. All units are in micrograms per square meter-hour ($\mu g/m^2 \cdot hr$).

DISCUSSION

One of the goals of the particleboard study was to determine if the rate of emission of various components found in the material was dependent on the relative amount of particleboard in the chamber (i.e., loading (L)) and/or the ventilation rate for the chamber (N). This was evaluated by plotting the data for emission rate ($\mu g/m^2 \cdot hr$) for each compound detected versus the chamber loading parameter N/L, where N is the number of air changes per hour, and L is the chamber loading in square meters of particleboard surface per cubic meter of chamber volume. These plots are presented in Figures 4 and 5. The results of this data analysis show that emission rates for at least some of the components respond to the air change/loading ratio.

The most pronounced response to product loading on the rate of emission of a chemical compound was exhibited by formaldehyde. Figure 6 is a plot of the formaldehyde emission rate versus concentration. Clearly, the emission rate and the concentration of formaldehyde in the air within the chamber were interrelated. The data show that the rate of formaldehyde emission in the case of N/L equal to 4.62, where minimum relative loading (maximum ventilation) occurs, is some 2.5 times greater than that for the worst case at an N/L of 0.46. Furthermore, the rate was found to be independent of the actual amount of particleboard in the chamber. Tests one and three were performed with five and one specimen boards, respectively, in the test chamber at equal N/L values of 1.38. Data obtained for all organics during these tests are plotted in Figures 7 and 8. For formaldehyde, test AY3 was calculated to have an emission rate of 168 $\mu g/m^2 \cdot hr$, while rates for the other three tests were between 139 and 141 $\mu g/m^2 \cdot hr$. The agreement among the latter three tests is far better than the experimental error for the analysis. The high value for the first test is possibly due to a higher than normal amount of aldehyde emissions from that set of boards, as also evidenced by the elevated benzaldehyde emission rate found. This formaldehyde result was confirmed by both laboratories involved in the interlaboratory study.

The concentration of benzaldehyde observed was approximately ten per cent of that of formaldehyde and near the median of the values determined for the other organics. This might indicate that the behavior of benzaldehyde should be closely related to that of other organics, but this was not the case. The trends observed for benzaldehyde were nearly identical to those seen for formaldehyde. As the N/L value decreased, the emission rate also decreased (see Figure 5). The fact that these two compounds change in a similar manner may be due to similarities in the transport and evaporation mechanisms that control their rate of emission. Perhaps these materials are more (or less) tightly

bound to the particleboard matrix than are the other organics, and thus are transported to or evaporated from the surface at different rates as compared to other compounds.

The rates of emission of the other organics do not appear to be influenced by ventilation rates and thus by concentrations in the air, as were benzaldehyde and formaldehyde. The highest concentrations of these compounds were lower than the lowest formaldehyde concentrations in most cases, but were of the same range as those of benzaldehyde. Both acetone and hexanal had observed concentrations for one test which exceeded the lowest formaldehyde values observed in another test, but they were only slightly greater. One possible explanation for the lack of change in emission rate for these materials is that the controlling factor in the emission of these substances is something other than their evaporation at the material surface. It may well be the case that the migration of these materials to the surface is much slower than the evaporation rate, for example.

These tests were not designed to provide enough facts to determine what mechanisms are involved in determining the rate of emission of organic compounds from a product. However, on the surface, they do not violate the classic kinetic principles discussed earlier, which predict that rate is dependent on the ratio of concentration at the surface of the particleboard to concentration in the air. As long as the concentration in the air is low compared to that in the material, the emission rate is essentially constant. As the concentration in the air increases, the emission rate declines in proportion. Also, if the rate limiting step is transport to the surface of the material, the rate may be constant.

CONCLUSIONS

The data generated indicate that the rate of emission of formaldehyde from particleboard is related to the ratio of the rate of ventilation to the loading (N/L). As the concentration of formaldehyde in the air increases, emission rates decline markedly. These data lead to the conclusion that, when designing the air circulation systems of homes and other buildings, consideration must be given to the rates of air exchange in the unit. If there is a high exchange rate, the concentrations of noxious vapors in the indoor air will be reduced by dilution. At the same time, the ventilation will remove formaldehyde from the sources faster. If the concentrations are allowed to build up, the time required for these agents to dissipate will be extended.

Except for benzaldehyde, there was no clear shift in emission rate with loading or ventilation rate for the other organic substances determined in these tests. That may be due to kinetic effects for these materials or to the low levels that were determined to be present. In some cases, these levels were near the limits of precision of the measurements. As stated above, at lower levels, the effects will be small when compared to the overall rate of emission.

ACKNOWLEDGEMENTS

This work was done under EPA contract 68-02-3988 to Acurex Corporation. The authors wish to thank S. N. Bailey of Acurex for her assistance in sample collection and analysis and R. G. Merrill and R. S. Steiber of the EPA's Air and Energy Engineering Research Laboratory for their work in providing the GC/MS identification of the organic compounds listed in Table 2.

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TABLE 1

TEST MATRIX

PARTICLEBOARD STUDY*

TEST ID	SAMPLE AREA (m^2)	AIR EXCHANGE (#/hr)	LOADING (m^2/m^3)	N/L RATIO**
AX3,AY3	0.325	2.71	1.96	1.38
AX4,AY4	0.195	0.54	1.17	0.462
AX2,AY2	0.130	3.61	0.78	4.62
AX1,AY1	0.065	0.54	0.39	1.38

* Temperature = 23°C; RH = 50%

** N = air exchange rate; L = material loading

TABLE 2

CHEMICAL COMPOUNDS AND CLASSES IDENTIFIED BY GC/MS
IN PARTICLEBOARD HEADSPACE

COMPOUND OR CLASS		MASS	MOLECULAR FORMULA
Acetonitrile		41	C_2H_3N
Dichloromethane	*	84	CH_2C_{12}
Acetone	**	58	C_3H_6O
2-Propanol	**	60	C_3H_8O
Methyl acetate	**	74	$C_3H_6O_2$
Butanal		72	C_4H_8O
2-Butanone		72	C_4H_8O
Acetic acid	**	60	$C_2H_4O_2$
An aldehyde or ketone		72	C_4H_8O
Methylpentane		86	C_6H_{14}
An aldehyde or ketone		86	$C_5H_{10}O$
Pentene		70	C_5H_{10}
2-Furaldehyde		96	$C_5H_4O_2$
Hexanal	**	100	$C_6H_{12}O$
Toluene		92	C_7H_8
Heptane		100	C_7H_{16}
Pinene isomer	**	136	$C_{10}H_{16}$
Pinene isomer		136	$C_{10}H_{16}$
Carene isomer	**	136	$C_{10}H_{16}$
Carene isomer		136	$C_{10}H_{16}$
Octane		114	C_8H_{18}
Benzaldehyde	**	106	C_7H_6O
Unidentified		?	
Dimethylhexadiene		110	C_8H_{14}
Unidentified		?	
Unidentified isomer		110	C_8H_{14}

* Possible laboratory contaminant
** Compounds confirmed by spectral and retention time matches

TABLE 3

CONCENTRATIONS DETERMINED FOR SEVEN ORGANIC CHEMICALS
(all values in $\mu g/m^3$)

TEST ID	FORMALDEHYDE	ACETONE	2-PROPANOL	2-BUTANONE	HEXANAL	BENZENE	BENZALDEHYDE
AY3	125.0	29.03	2.81	1.59	7.63	2.53	14.29
AY4	228.6	106.51	21.28	5.35	64.92	15.47	26.91
AY2	52.8	10.25	1.25	0.87	4.48	1.16	3.46
AY1	106.6	33.80	3.92	2.72	23.04	6.22	9.15
AX3	104.5	25.44	3.84	0.94	15.34	4.16	10.07
AX4	205.7	82.92	11.26	3.12	52.51	12.96	20.45
AX2	50.0	6.58	0.62	0.68	4.34	1.72	4.11
AX1	107.4	22.22	6.45	1.36	13.37	3.73	7.75

TABLE 4

DETECTION AND QUANTITATION LIMITS FOR GC ANALYSIS
(all values in $\mu g/m^3$)

COMPOUND	LIMIT OF DETECTION	LIMIT OF QUANTITATION
FORMALDEHYDE	6.2	21
ACETONE	0.33	1.1
2-PROPANOL	0.20	0.67
2-BUTANONE	0.20	0.67
HEXANAL	0.23	0.75
BENZENE	0.13	0.42
BENZALDEHYDE	0.20	0.67

TABLE 5

EMISSION RATES FOR SEVEN ORGANIC COMPOUNDS
(all values in $\mu g/m^2 \cdot hr$)

TEST ID	EMISSION RATE	PRECISION*	EMISSION RATE	PRECISION*
FORMALDEHYDE			ACETONE	
AY3	167.5	25.5	38.9	7.9
AY4	101.3	5.8	47.2	4.2
AY2	236.3	20.0	45.9	6.1
AY1	139.8	5.9	44.3	6.4
AX3	141.3	7.3	34.4	7.6
AX4	88.6	0.0	35.7	7.2
AX2	223.2	2.2	29.4	2.7
AX1	139.8	1.7	28.9	1.1
2-PROPANOL			2-BUTANONE	
AY3	3.76	1.9	2.13	0.5
AY4	9.43	4.5	2.37	0.6
AY2	5.58	0.2	3.91	1.0
AY1	5.14	0.9	3.57	0.8
AX3	5.19	1.5	1.27	0.2
AX4	4.85	0.5	1.34	0.1
AX2	2.77	0.6	3.03	0.3
AX1	8.40	1.1	1.77	0.0
HEXANAL			BENZALDEHYDE	
AY3	10.23	0.9	19.15	0.11
AY4	28.76	1.0	11.92	2.79
AY2	20.04	3.3	15.48	1.86
AY1	30.21	0.2	11.99	1.22
AX3	20.73	0.4	13.60	5.92
AX4	22.62	0.4	8.81	1.09
AX2	19.37	0.8	18.34	0.35
AX1	17.40	0.3	10.08	0.87

TEST ID	EMISSION RATE	PRECISION*
BENZENE		
AY3	3.39	0.23
AY4	6.85	0.39
AY2	5.21	0.60
AY1	8.15	0.70
AX3	5.62	0.90
AX4	5.58	0.04
AX2	7.70	5.02
AX1	4.85	0.01

* Precision cited is the standard deviation of the analyses for the test.

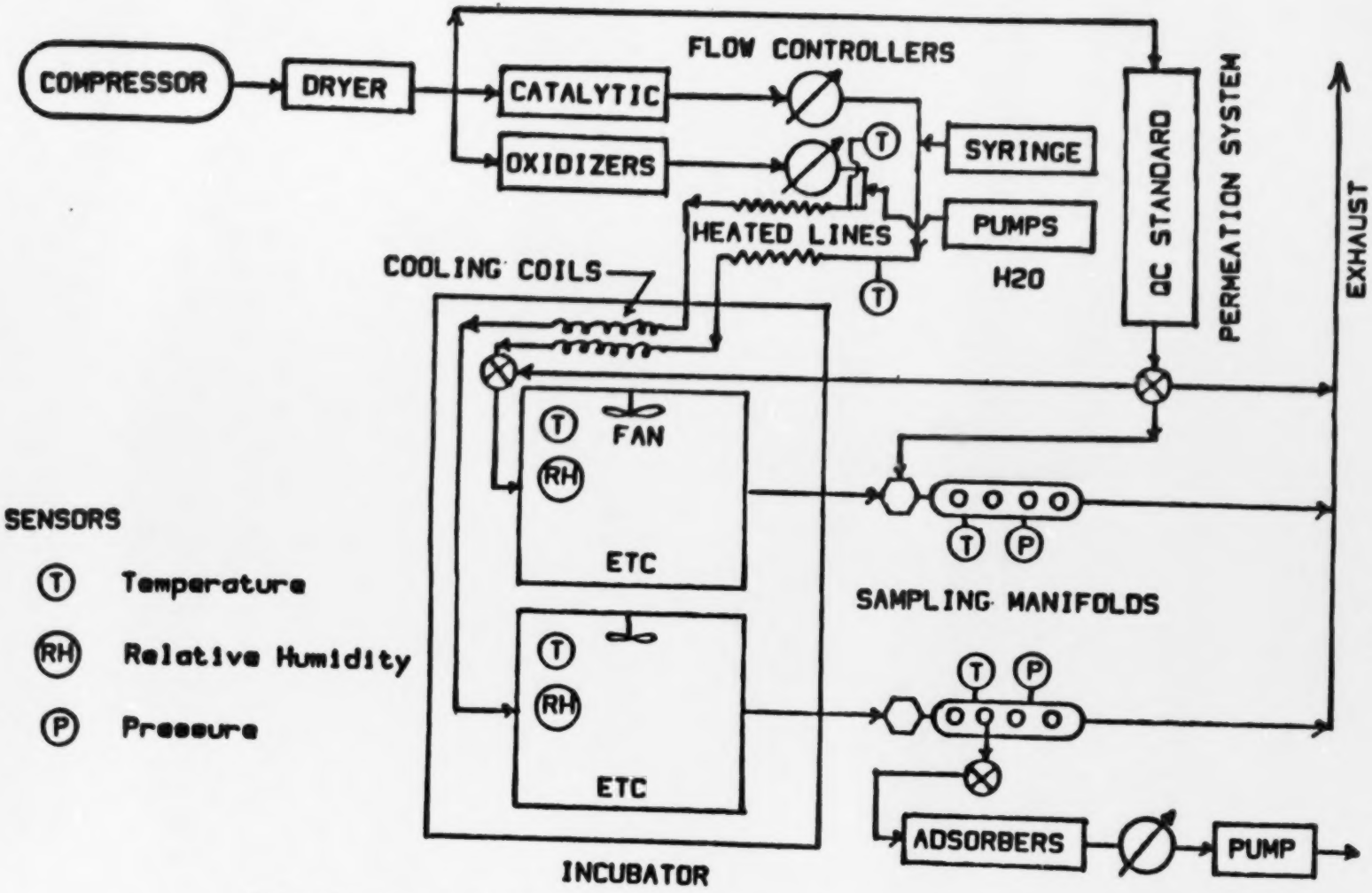

Figure 1. Schematic diagram of the EPA environmental test chamber facility.

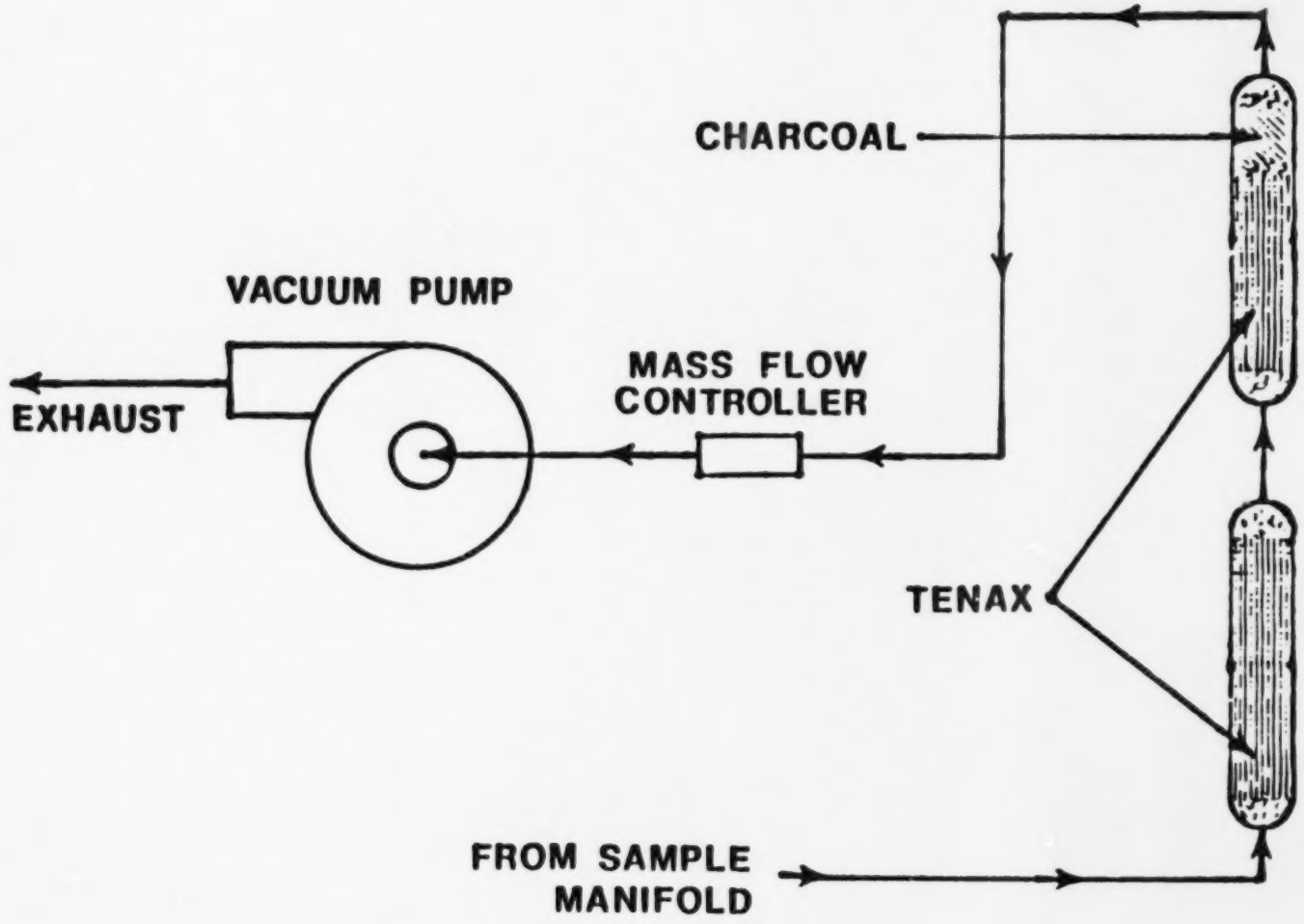

Figure 2. Volatile organic sampling system.

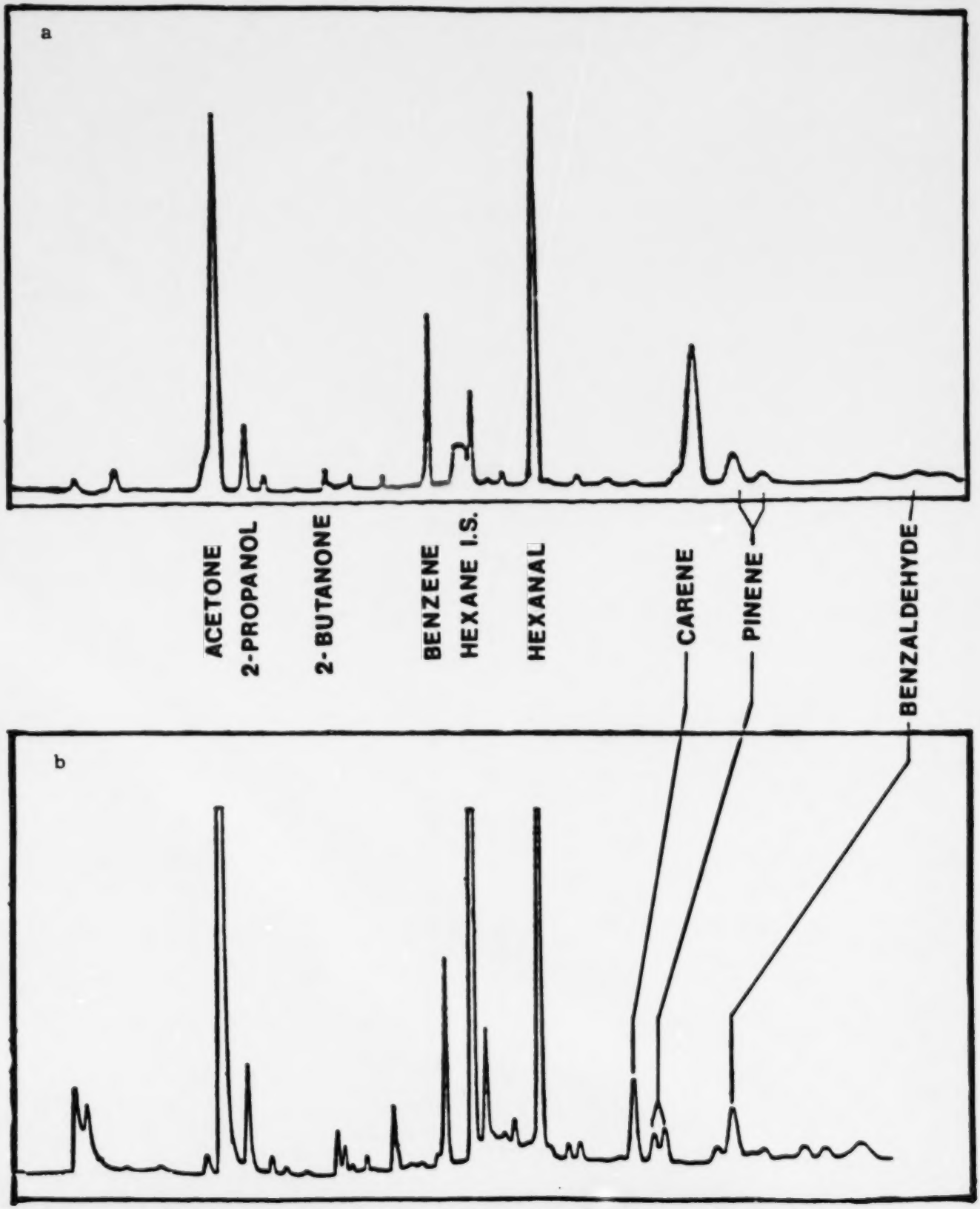

Figure 3. (Top) Qualitative GC/MS analysis of particleboard; (Bottom) GC trace of particleboard emission sample from test chamber.

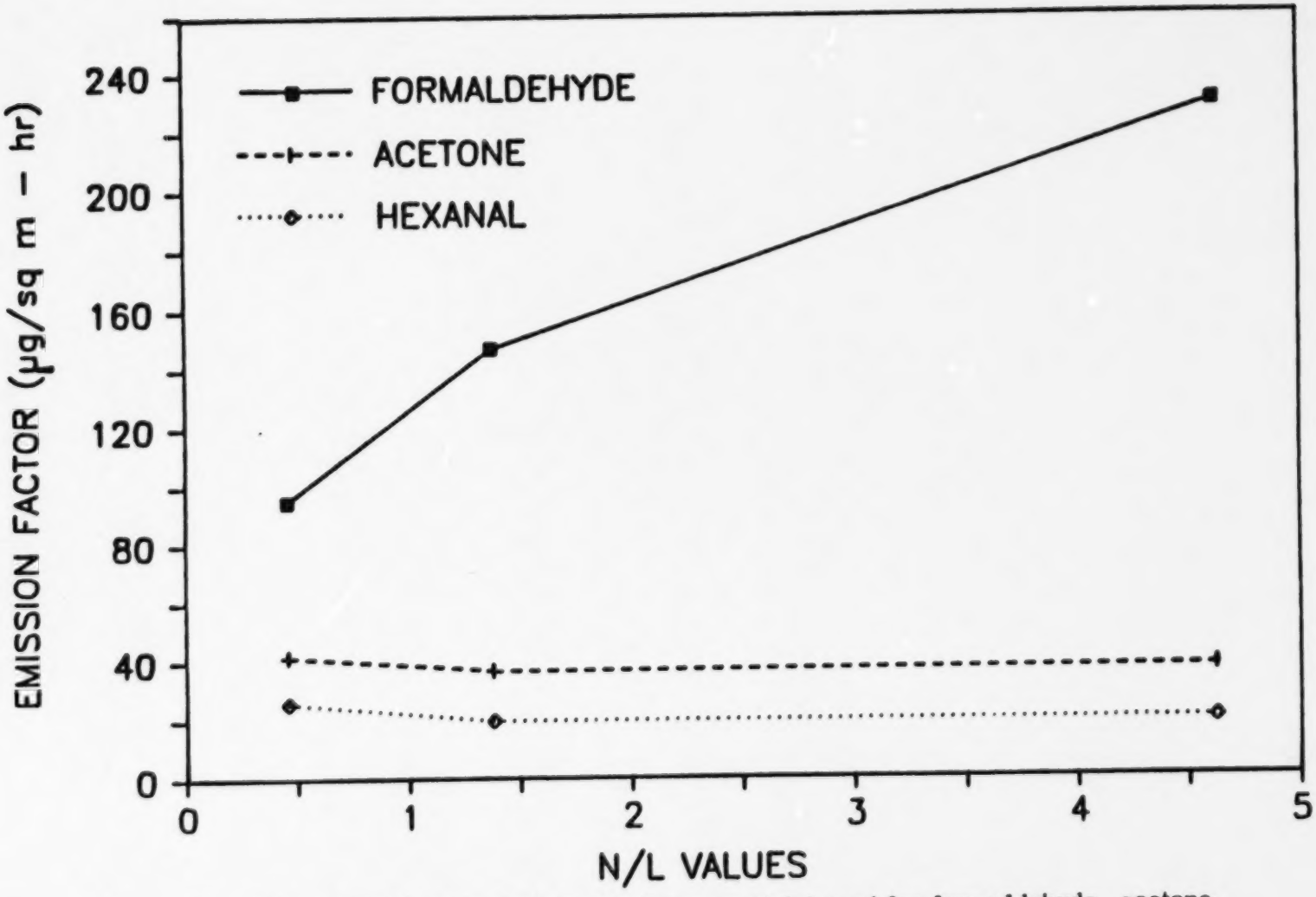

Figure 4. Effect of N/L on emission rate from particleboard for formaldehyde, acetone, and hexanal.

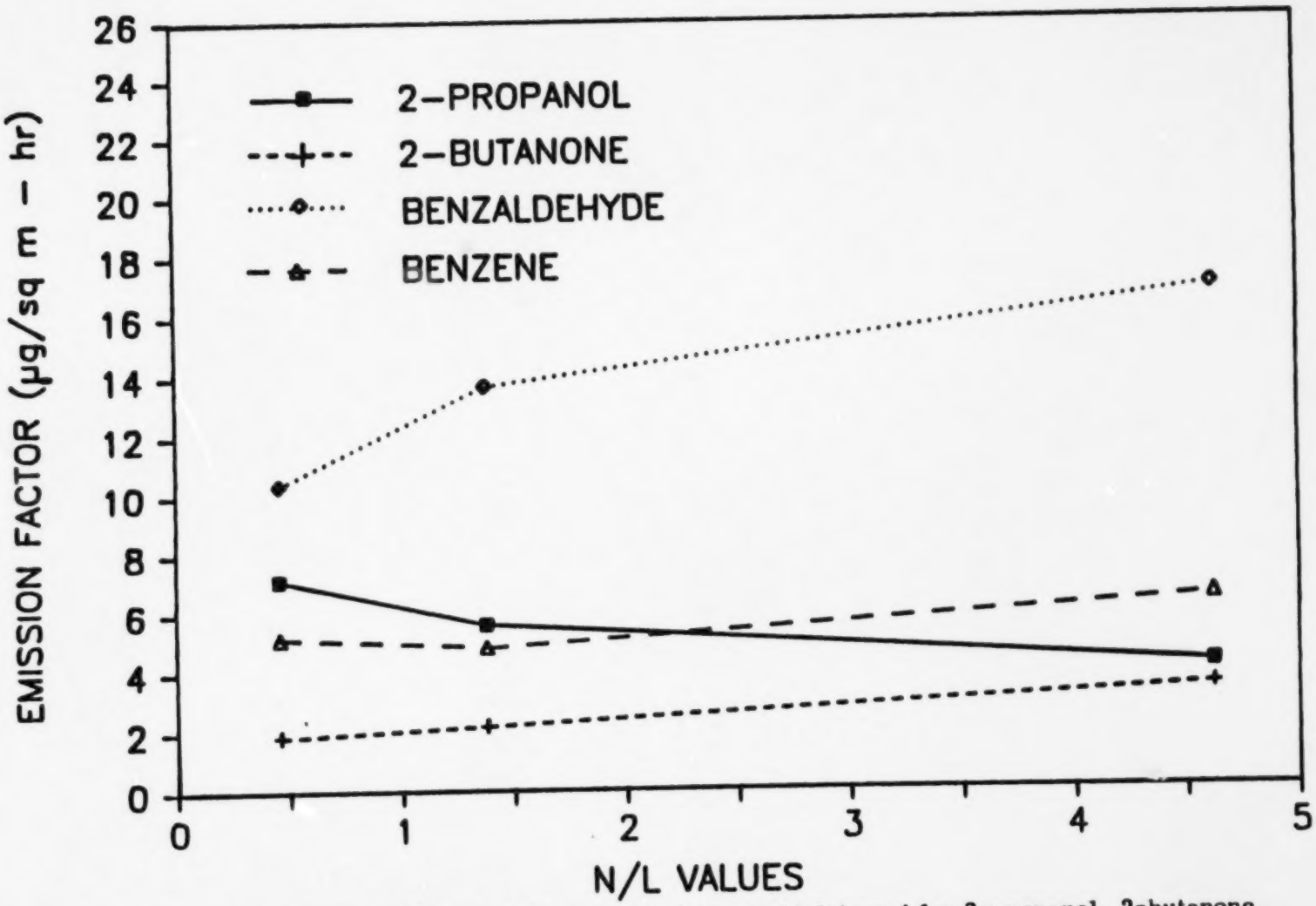

Figure 5. Effect of N/L on emission rate from particleboard for 2-propanol, 2-butanone, benzaldehyde, and benzene.

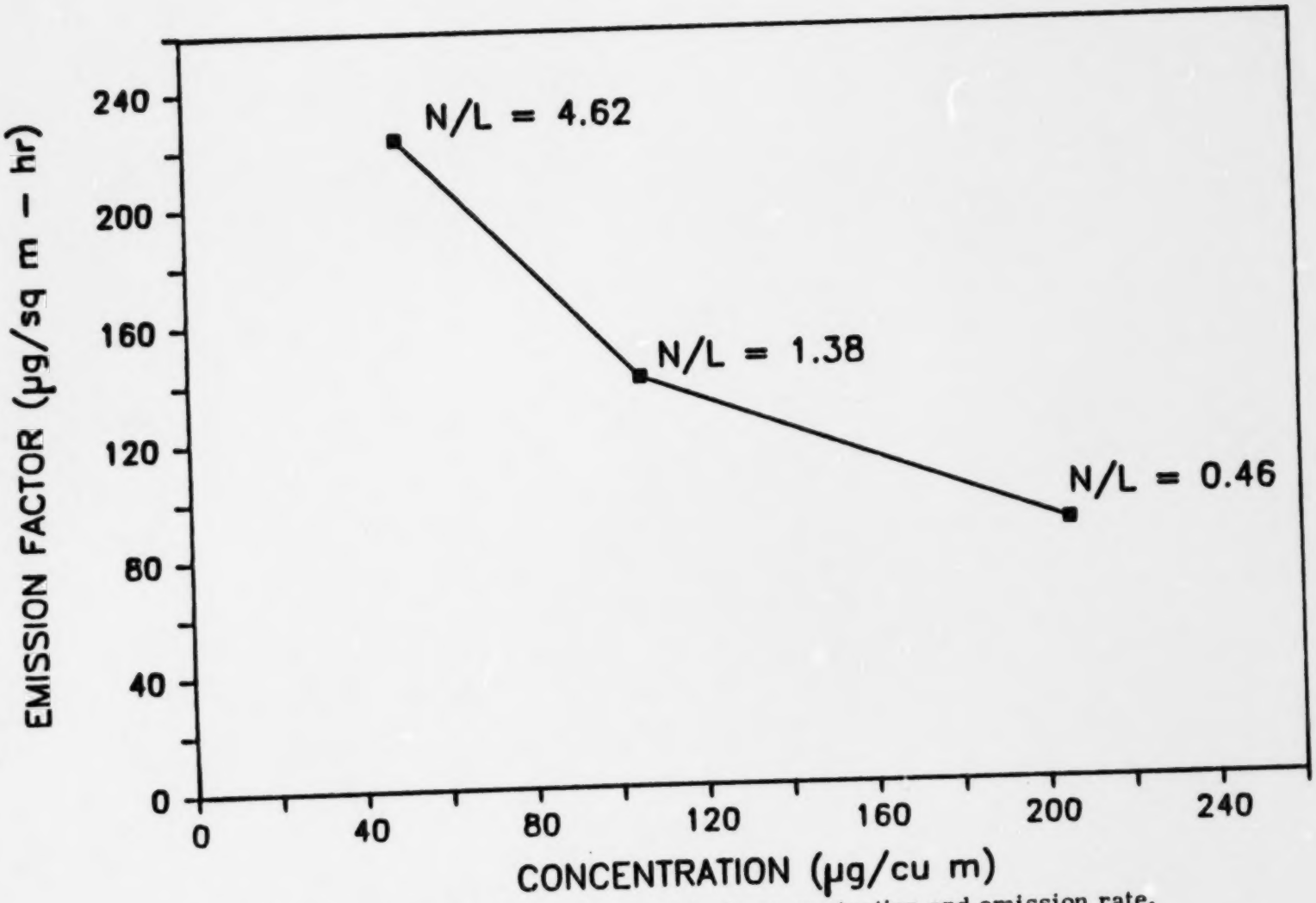

Figure 6. Relationship between formaldehyde concentration and emission rate.

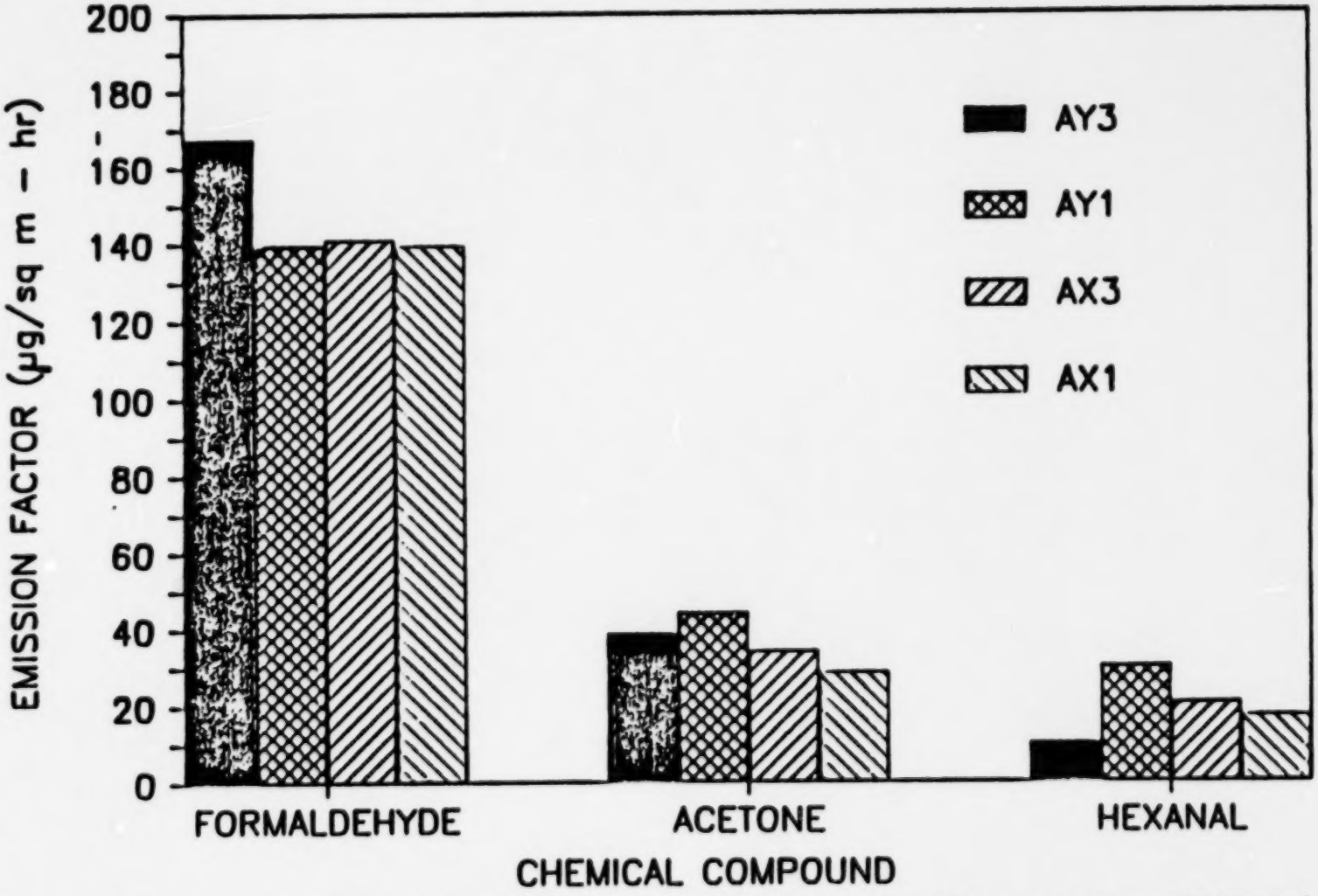

Figure 7. Particleboard emission rates at N/L of 1.38 for formaldehyde, acetone, and hexanal.

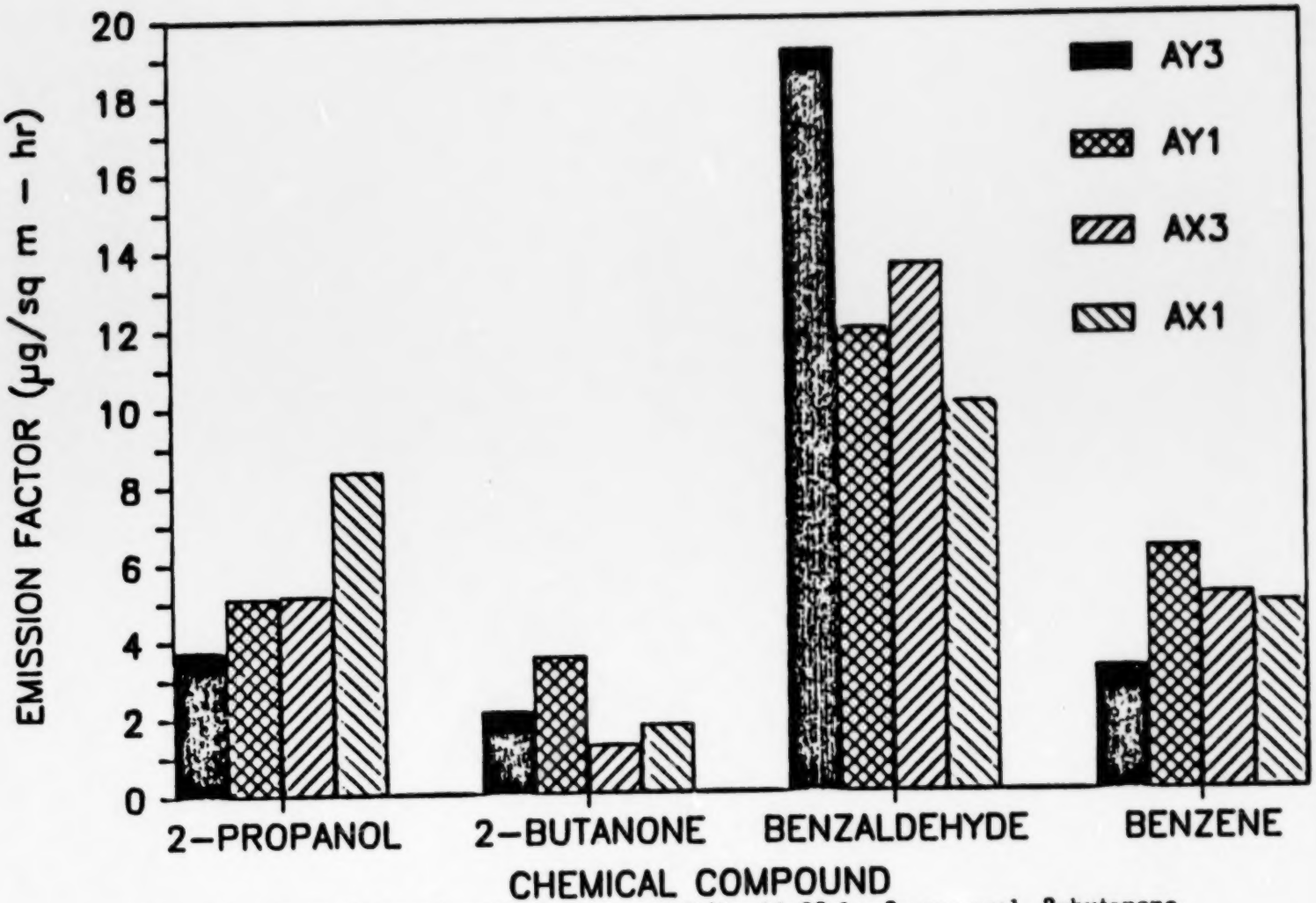

Figure 8. Particleboard emission rates at N/L of 1.38 for 2-propanol, 2-butanone, benzaldehyde, and benzene.